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The Ohio State University

ADVANCED ADAPTIVE
ANTENNA TECHNIQUES

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This report describes progress under Naval Air Systems Command Contract N00019-80-C-0181 during the fourth quarterly period. Research on advanced adaptive antenna techniques is summarized.

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I. INTRODUCTION

This report describes progress under Naval Air Systems Command Contract N00019-80-C-0181 during the fourth quarterly period. This contract involves adaptive array studies in two areas: (1) the effects of element patterns and signal polarization on adaptive array performance, and (2) the capability of pulsed and swept CW jamming against adaptive arrays. In addition, a monograph on adaptive arrays is being prepared under this contract.

During the fourth quarterly period, we have done work in both research areas and on the monograph. Progress on each of these is described below.

II. PROGRESS

1. The Effects of Element Patterns on Array Performance

Our work on element patterns for adaptive arrays has been continued. We have formulated a simple design procedure for choosing element patterns in an adaptive array. The method can be used when the design objective is to provide sector coverage with the array. A paper describing this method has been written and submitted for publication to the IEEE Transactions on Antennas and Propagation[1].

The method is the following. One starts with an array consisting of an initial set of elements, chosen by some means. One evaluates the performance of this array, to determine if there are particular signal arrival angles and polarizations where the output signal-to-interference-plus-noise ratio (SINR) is poor. One then augments the array by adding extra elements one at a time, to improve the SINR for these angles and polarizations. The conditions that must be satisfied by the pattern of each new element to obtain maximum benefit are determined in the paper.

Such a method can be used because the SINR obtained from an adaptive array cannot decrease when additional elements are added, as long as the original element patterns do not change. The SINR is a non-decreasing function of the number of elements, for all signal arrival and polarizations. Thus, once a set of elements has been found that

yields adequate performance over part of the sector, one does not have to worry that adding new elements will reduce the performance in this sector. The new elements can be chosen to improve the SINR in other regions where the original array did not perform well.

As an example of this design method, consider the array of two dipoles located and oriented as shown in Figure 1. Let us consider the performance of this array when it receives linearly polarized signals whose electric field and direction of arrival lie in the plane of the paper. Let θ be defined as shown in Figure 1. Assume the patterns of the two dipoles are

$$f_1(\theta) = \cos(\theta-60^\circ)$$

and

$$f_2(\theta) = \cos(\theta+60^\circ)$$

Assume a desired signal is incident on the array from angle θ_d and an interference signal from angle θ_i. It is shown in [2] that this pair of dipoles has a grating null problem when θ_d=22.3° and θ_i=39°. The lower curve in Figure 2 shows the SINR as a function of θ_i when θ_d=22.3° (and for SNR=0 dB and INR=40 dB). The effect of the grating null may be seen. Interference at θ_i=39° not only causes a null at 39°, it causes another null at 22.3° (the grating null). When θ_i approaches 39°, the grating null approaches 22.3° where the desired signal is, so the SINR is low.

To improve the performance for the case θ_d=22.3° and θ_i= 39°, we add another dipole. Suppose the new dipole has a pattern $f_3(\theta) = \cos(\theta-\theta_0)$ and is located a distance d to the right of dipole 1 in Figure 1. In the paper, it is shown how to determine the values of θ_0 and d that give the greatest SINR improvement. One finds that θ_0 should be 2.8° and d should be 2λ. When the third dipole is added with these parameters, the array is as shown in Figure 3. The SINR performance for this 3-element array is shown as the top curve in Figure 2. It is seen how the performance around θ_i=39° has been improved.

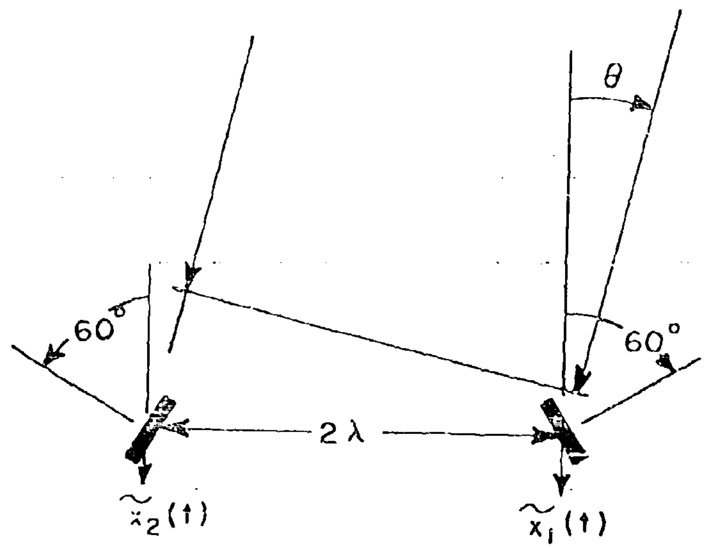

Figure 1. A 2-dipole array.

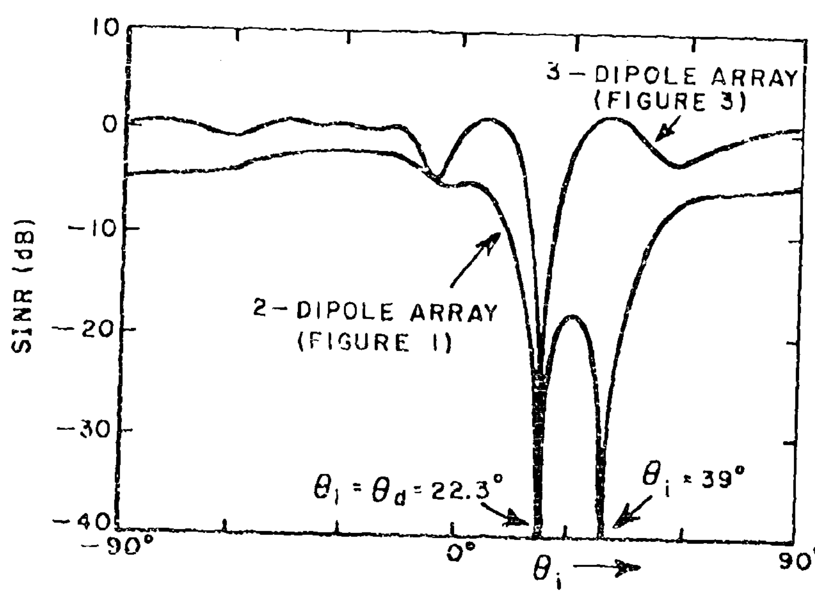

Figure 2. SINR vs. θ_i.
θ_d=22.3^o, ξ_d=0 dB, ξ_i=40 dB

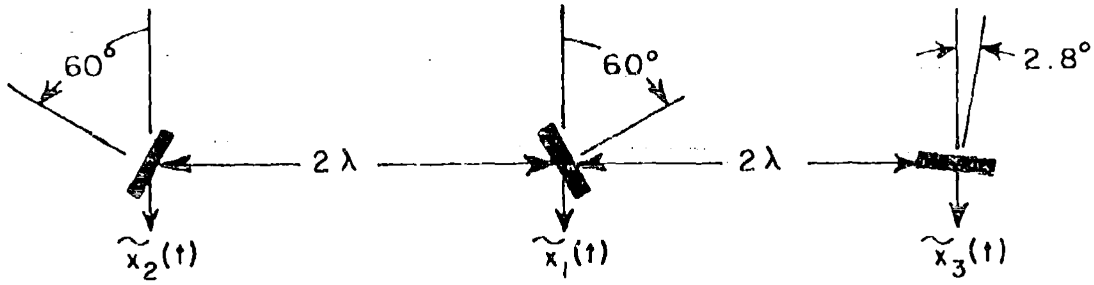

Figure 3. The 3-dipole array.

2. The Effects of Pulsed Jamming on an Adaptive Array

During the final quarter we have completed our studies of the effects of a single pulsed jammer on an adaptive array. Programs developed last quarter have been used to evaluate the effect of signal arrival angles, pulse repetition frequency, pulse width, desired signal-to-noise ratio, and interference-to-noise ratio on the adaptive array behavior. The frequency dispersion of the array has been evaluated, and the effect of pulsed jamming on bit error rate when the array is used in a digital communication system has been studied.

One interesting result we have discovered is that pulsed jamming does not produce phase modulation on the desired signal, regardless of signal arrival angles, pulse repetition rate, pulse width, or signal-to-noise ratios.

In general, our results show that pulsed interference is not as great a problem for an adaptive array as we had imagined. It turns out that desired signal envelope modulation produced by pulsed jamming is small unless the jammer arrives very close in angle to the desired signal (in which case CW jamming is also a problem). When the adaptive

array is used in a digital communication system, pulsed jamming produces a noticeable, but not disastrous, increase in the bit error probab ity. A large increase is produced only if the jammer arrives very se in angle to the desired signal, and in this case CW jamming would nave the same effect on bit error rate. Moreover, the pulsed jammer must have all its parameters properly chosen to produce much increase in bit error probability. The pulse repetition frequency, pulse width and power of the jammer must all have the right values, which are all functions of the jammer and desired signal arrival angles, the desired signal power and the feedback loop gain used in the array. Thus, optimizing the jammer parameters appears to be difficult in practice because the optimum values depend on several factors unknown to the jammer. Moreover, even when optimized, the effect of the jammer is not disastrous.

For these reasons, we have concluded that pulsed jamming does not represent an unusual threat to the adaptive array.

The results of this study are described in detail in a recent technical report [3].

3. Other Types of Modulated Interference

During the final quarter, we have begun studies to evaluate the effect on the array of interference signals consisting of multiple CW tones. This class of signals includes many types of interference; any signal with periodic envelope or angle modulation can be represented in this form. For example, a swept CW signal (with periodic sweeping) is of this type.

The first step has been to determine the weight behavior with such interference signals. With this type of signal, the array weights satisfy a system of first-order differential equations similar to the well-known Mathieu equation (which arises in problems of wave propagation in periodic media) except that they are first order and are vector equations. During the quarter, a method has been found for obtaining the periodic steady-state solution to these equations in closed form. The method consists of first expressing the weight vector as a

Fourier Series and deriving an infinite set of recursion relations for the coefficients. The recursion relations are then solved by enforcing a convergence condition on the series and making use of an infinite continued fraction. To date, this method has been used to calculate the weight behavior with a simple envelope modulated interference signal.

We plan to continue this work during the continuation contract.

4. Monograph

The monograph has progressed during the last quarter of the contract. At this writing a draft of Chapter IV has been completed and most of Chapter V has been done. Additional work is needed in polishing the manuscript and then we will be ready to go to a publisher.

III. PAPERS PUBLISHED

During the current year, five papers that were submitted during the previous contract (N00019-79-C-0291) have either appeared or are about to appear:

(1) R.T. Compton, Jr., "Pointing Accuracy and Dynamic Range in a Steered-Beam Adaptive Array," IEEE Transactions on Aerospace and Electronic Systems, AES-16, 3 (May 1980), p. 280.

(2) A. Ishide and R.T. Compton, Jr., "On Grating Nulls in Adaptive Arrays," IEEE Transactions on Antennas and Propagation, AP-28, 4 (July 1980), p. 467.

(3) R.T. Compton, Jr., "On the Performance of a Polarization Sensitive Adaptive Array," accepted for publication in IEEE Transactions on Antennas and Propagation and final manuscript in.

(4) R.T. Compton, Jr., "The Tripole Antenna - An Adaptive Array with Full Polarization Flexibility," accepted for publication in IEEE Transactions on Antennas and Propagation and final manuscript in.

(5) R.T. Compton, Jr., "The Effect of Differential Time Delays in the LMS Feedback Loop," IEEE Transactions on Aerospace and Electronic Systems, AES-17, 2 (March 1981), p. 222.

During the present contract (N00019-80-C-0181), three new papers have been submitted for publication:

(1) R.T. Compton, Jr., "The Effect of Integrator Pole Position on the Performance of an Adaptive Array," accepted for publication in IEEE Transactions on Aerospace and Electronic Systems.

(2) R.T. Compton, Jr., "A Method of Choosing Element Patterns in an Adaptive Array," submitted to IEEE Transactions on Antennas and Propagation.

(3) R.T. Compton, Jr., "The Effect of a Pulsed Interference Signal on an Adaptive Array," submitted to IEEE Transactions on Aerospace and Electronic Systems.

IV. REFERENCES

[1] R.T. Compton, Jr., "A Method of Choosing Element Patterns in an Adaptive Array," submitted to IEEE Trans. on Antennas and Propagation.

[2] A. Ish'de and R.T. Compton, Jr., "On Grating Nulls in Adaptive Arrays," IEEE Trans., AP-28, 4 (July 1980), p. 467.

[3] R.T. Compton, Jr., "The Effect of a Pulsed Interference Signal on an Adaptive Array," Report 712684-8, April 1981, The Ohio State University ElectroScience Laboratory, Department of Electrical Engineering; prepared under Contract N00019-80-C-0181 for Naval Air Systems Command.